Amendment to the Specification

Please replace the paragraph on page 1, lines 3-7, with the following amended paragraph:

A3

The present invention relates to image processing, in particular to methods and apparatus for registration and merging of a plurality of overlapping two-dimensional (2D) images of three-dimensional (3D) scenes, especially in cases where the 2D images are related to the 3D scenes by a projective (or camera) transformation. The invention also ~~related~~ relates to apparatus for performing the disclosed image processing.

Please replace the paragraph on page 2, lines 13-15, with the following amended paragraph:

A4

The objects of the present invention are to provide apparatus and methods which simply and stably determine an accurate projective transformation relating two images from pairs of corresponding points identified in each image of the pair.

Please replace the paragraph on page 2, lines 16-21, with the following amended paragraph:

A5

Achieving these objects by the present invention depends on the discovery that a projective transformation can be better determined from a plurality of pairs of corresponding points in both images when the numerical ranges of the coordinates of these corresponding points ~~is~~ are minimized. With minimum numerical ranges of the coordinates, errors arising from ~~terms~~ non-linear terms in the coordinates are reduced in comparison with other methods which are ignorant of this discovery.

Please replace the paragraph on page 2, lines 22-28, with the following amended paragraph:

A6

The present invention minimizes these coordinate ranges prior to determining the projective transformation relating a pair of images. In one alternative, an original

A6 cont'd

coordinate system is chosen in each image in advance to minimize these coordinate ranges. This choice can be made, for example, by finding a coordinate origin for which the sum of the radius vectors to the feature points is a minimum. Such a coordinate origin can be found by a search technique. In this alternative, the projective transformation is determined directly in the original coordinate system.

Please replace the paragraph on page 3, lines 17-29, with the following amended paragraph:

A7

In detail, these objects are achieved by the following embodiments of this invention. In a first embodiment, the present invention includes a method for merging a pair of overlapping two-dimensional (2D) images, said images being projections of a single three-dimensional (3D) scene, said method comprising: selecting at least four feature points in the 3D scene, finding the 2D ~~coordinate~~ coordinates of the points in both images corresponding to the selected feature points, the 2D coordinates being found with respect to original coordinate systems in the two images, translating the original coordinate systems of the two images in order to substantially minimize the average coordinate ranges of the 2D coordinates found, determining the parameters of a substantially optimal projective transformation relating the corresponding translated coordinates in the two ~~image~~ images, determining the parameters of the projective transformation for application in the ~~untranslated~~ non-translated coordinate systems of the two images, and merging the two images by transforming one image according to the projective transformation and combining the transformed image with the other image.

Please replace the paragraph beginning on page 3, line30 through page 4, line 2, with the following amended paragraph:

A8

In a second embodiment, the invention includes an apparatus for merging a pair of overlapping two-dimensional (2D) images, said images being projections of a single three-dimensional (3D) scene, said apparatus comprising: means for obtaining a pair of

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2D images, a processor responsive to the means for obtaining images and configured to perform the methods of the first embodiment, and a display for viewing the pair of images merged by the processor.

***Please replace the paragraph on page 4, lines 3-9, with the following amended paragraph*:**

A9

In a third embodiment, the invention includes an x-ray apparatus for merging a pair of overlapping two-dimensional (2D) images, said images being projections of a single three-dimensional (3D) scene, said apparatus comprising: an x-ray source for projecting a beam of x-rays through an object to be examined, an x-ray detector for obtaining digital x-ray images which are projections of the object, a processor responsive to pairs of overlapping x-ray images obtained by the x-ray detector and configured to perform the methods of the first embodiment, and a display for viewing the pair of images merged by the processor.

***Please replace the paragraph on page 4, lines 10-12, with the following amended paragraph*:**

A10

In a fourth embodiment, the invention includes a computer readable medium comprising encoded program instructions for causing a processor to perform the methods of the first embodiment.

***Please replace the paragraph on page 5, lines 9-15, with the following amended paragraph*:**

A11

Digital 2D images of 3D scenes can be obtained for input to the apparatus of this invention for processing by the methods of the present invention by any means known in the art. One exemplary means is to simply scan standard photographs with a digital scanner. Fig. 1 illustrates another exemplary means, digital PC camera 21 which includes lens system 23 for optical imaging and CCD array 22 for conversion of an optical image to digital signals for input to PC ~~28~~ 27. As illustrated, an image of a 3D scene including arrow 31 is projected onto CCD array 22 through lens system 23.

Please replace the paragraph on page 5, lines 16-23, with the following amended paragraph:

A12

Fig. 2 illustrates use of digital camera 32, perhaps of greater capability than PC camera 21, which is mounted on tripod 33 for rotation about axes 34 and 35 in order to pan across extended scene 37. Since camera 32 can form images of only a limited part of the 3D scene at one time, for example, of objects in cone 36 which is projected onto a digital pickup in camera 32, forming an image of entire extended scene 37 requires ~~than~~ that multiple individual images be merged into a composite image by the image processing apparatus according to the present invention. Digital camera 32 can be responsive to selected bands of electromagnetic radiation, for example to infrared or to visible light.

Please replace the paragraph beginning on page 5, line33 through page 6, line 5, with the following amended paragraph:

A13

For example, patient 12 can be longitudinally displaced along direction 11 on patient table 8 by motor means 9. The x-ray source and the x-ray detector, mounted on C-arm 3 that is in turn mounted by collar 4 on support 5, are capable of coordinated rotation about ~~tow~~ two perpendicular horizontal axes 12' and 12". Finally, support 5 can be longitudinally translated along rails 7 or rotated about vertical axis 6. The present invention is also applicable to x-ray apparatus with other means for jointly moving the x-ray source and the x-ray detector for rotation or translation.

Please replace the paragraph on page 6, lines 6-18, with the following amended paragraph:

A14

To obtain a composite image of an extended region of the patient, for example, of the patient's legs, a plurality of individual images formed during panning of the x-ray apparatus about one or more of these degrees of freedom must be merged. Fig. 4 illustrates in a diagrammatic fashion the formation of limited images and the merging of consecutive and overlapping images into an assembled extended image. A patient's

A14 Cont

leg 16 is shown on patient table 8. Vertical support 5 is moved along rails 7, so that the x-ray source is moved in the direction of arrow 14. As the x-ray source is moved, x-ray beam 15 is intermittently directed at the patient's leg. Together with the x-ray source, the x-ray detector is also moved so as to face the x-ray source when the patient is irradiated. Whenever the patient's leg is irradiated, a limited x-ray image is formed on the entrance screen of the image intensifier. Thus, collection 40 is formed of consecutive images 41_1 to 41_n which mutually overlap to various degrees. The overlap between sub-images depends on the displacement between positions of the x-ray source at the irradiation for forming said sub-images.

Please replace the paragraph on page 6, lines 19-28, with the following amended paragraph:

A15

An apparatus configured according to the present invention accurately merges the sub-images of collection 40 into assembled image ~~42~~ 44, which contains a shadow-image of the patient's entire legs. For example, images 41_{n-1} and 41_n need to be brought into spatial registration before merging, mis-registration being due, for example, to planned or accidental changes in the orientation of x-ray beam 15 when the two projection images are formed. Mis-registration is reflected in area 42 of overlap where, for example, point 43_{n-1} is at a different location than point 43_n, although both points represent the same feature in patient leg 16. Mis-registration is corrected by determining a projective transformation ~~the~~ that relates images 41_{n-1} and 41_n so that points 43_{n-1} and 43_n are at the same spatial position. Images in spatial registration can be merged without blurring.

Please replace the paragraph on page 7, lines 22-31, with the following amended paragraph:

A16

Turning now to a more detailed description of the individual steps of the methods, selection of feature points in the overlapping region of a pair of overlapping 2D images at step 52 can, for example, be done manually. Here, a user, for example,

A16 Con't

at apparatus 29, selects N easily distinguishable points in the 3D scene that appear in both images. Then these feature points are identified in both images, and their coordinates are measured in both the images. This results in N pairs of 2D coordinates, each pair being the corresponding coordinates of a feature point. These are represented by the pairs:

$$\mathbf{u}_i = (u_{1,i} \quad u_{2,i})^T, \quad \mathbf{v}_i = (v_{1,i} \quad v_{2,i})^T, \quad i = 1, \ldots, N \qquad \cancel{(1)}\ \underline{(1)}$$

Here, the $\mathbf{u}_i$ are the coordinates of points in one image, and the $\mathbf{v}_i$ are the coordinates of corresponding points in the other image.

***Please replace the paragraph beginning on page 7, line32 through page 8, line 5, with the following amended paragraph*:**

A17

Alternatively, the feature points may be selected automatically by the image processing apparatus. One automatic method proceeds by first sparsely sampling points in the overlapping region of the image, then using matching or correlation of locally surrounding blocks of points to determine candidate pairs of sampled points that should ~~corresponding~~ correspond to the same 3D scene point, and finally retaining only those candidates pairs that have sufficient surrounding image structure for accurate block matching or correlation. See, *e.g.*, Schultz et al., 1999, IEEE International Conference on Acoustics, Speech and Signal Processing, vol. 4, pp. 3265-3268.

***Please replace the paragraph on page 8, lines 6-13, with the following amended paragraph*:**

A18

Another automatic method proceeds by first constructing multiresolution decomposition of the images by self-similar discrete wavelet transforms, then selecting candidate image points having local maximums of the pixel-value gradient greater than a threshold where the pixel-value gradient is prominent at all resolutions, and finally retaining only those pairs of candidates points that have sufficiently cross-correlated locally surrounding blocks of points, and thereby that should correspond to the same

A18

OOK'd feature in the 3D scene. The conditions imposed on the pixel-value gradient are to insure that there is sufficient image structure surrounding the candidate points for accurate cross-correlation.

Please replace the paragraph on page 8, lines 14-25, with the following amended paragraph:

The next steps determine a single substantially optimal projective transformation that relates the pairs of corresponding points in the overlapping region of two images. A projective transformation best models the relation between the pairs of overlapping images because, as detailed above, the images are obtained by devices that project a 3D scene onto the 2D images. A projective transformation linking pairs of corresponding points is represented ~~in the following~~ by the following matrix equation.

A19

$$\mathbf{v}_i = \frac{\mathbf{A}\cdot\mathbf{u}_i + \mathbf{T}}{\mathbf{C}^T\cdot\mathbf{u}_i + 1} \tag{2}$$

This transformation has the following matrix parameters (A, C, T) which are determined by their eight matrix elements.

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}, \quad \mathbf{C} = \begin{pmatrix} c_1 & c_2 \end{pmatrix}^T, \quad \mathbf{T} = \begin{pmatrix} t_1 & t_2 \end{pmatrix}^T \tag{3}$$

This transformation is selected to hold for all N pairs of corresponding 2D coordinates previously selected.

Please replace the paragraph on page 9, lines 11-17, with the following amended paragraph:

A20

It is an important discovery on which this invention in founded that the stability and accuracy of the solution for the parameter matrix, **P**, is considerably improved if the coordinate translations are chosen in order to minimize, on average, the numerical range of all the coordinates values of the corresponding feature points in each image. Such minimization is effective because it reduces computational errors in the terms

A20
cont

involving the products of feature point coordinates appearing in the matrices $\mathbf{U}_i$, these product terms being apparent in ~~Eqns.~~ Equations 4A, 4b and 5.

Please replace the paragraph on page 10, lines 6-12, with the following amended paragraph:

A21

In an alternative embodiment, this translation can be avoided in the original coordinate systems ~~in~~ if the two images are chosen so that the numerical ranges of the feature point coordinates are initially minimized. This choice can be done by searching for optimum placement of the origins of the coordinate systems in the two images. This search for the coordinate origin can seek to minimize any of ~~Eqns.~~ Equations 9a, 9b or 9c, or another metric such as the mean square distance of the feature points from the coordinate origin. If the coordinate systems are so chosen, the projective transformation can be directly determined.

Please replace the paragraph on page 12, lines 5-11, with the following amended paragraph:

A22

The methods of this invention are readily implemented on image processing apparatus, for example, apparatus 29, by programming the above steps in an appropriate programming language, for example, C or FORTRAN. Initialization and termination activities of such programs occur in steps 50 and 58, respectively. Optionally, numerical algebra packages, such as LINPACK, can be used to ~~routine~~ routinely perform various ones of the above steps, such as necessary matrix multiplication, finding the SVD and so forth. One of skill in the art can readily and routinely perform such programming in view of the above description.

Please replace the paragraph on page 13, line 1, with the following amended paragraph:

A23

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